THE EMERGENCE OF BIOENGINEERING DEPARTMENTS IN THE UNITED STATES: DENSITY DEPENDENCE OR STRATEGIC INTERACTION?

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THE EMERGENCE OF BIOENGINEERING DEPARTMENTS IN THE UNITED STATES: DENSITY DEPENDENCE OR STRATEGIC INTERACTION?

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SUMMARY

This paper analyzes the founding rate of bioengineering departments in the United States. It takes the density dependence model from organizational ecology literature as the starting point of the analysis. This model predicts that founding rates of organizational populations are driven by population density, which represents processes of legitimation and competition, and by external environmental factors. The analysis finds support for density dependence predictions about the effect of population density on the founding rate of bioengineering departments. Further, this analysis finds that funding from the Whitaker Foundation has a significant positive impact on the founding rate of departments. The density dependence model is based on assumptions that individual actors are limited in their ability to act strategically and that competition is diffuse. In light of these assumptions and the threat to validity that would be posed if they were incorrect, the paper presents a discussion of strategic interaction and direct competition. I use an acceleration analysis comparison to conduct an initial study of the existence of endogenous interaction within the population of bioengineering departments. I find evidence of endogenous interaction through a process of cumulative social learning.

CHAPTER 1

INTRODUCTION

The biotechnology industry is characterized by a high level of interdependence between organizations. The nature of the industry is such that no single organization has access to or control over all the relevant capabilities. Studies have found the presence of local universities and star scientists (Zucker et al, 1998) and the density of local biotechnology-relevant degree programs (Stuart and Sorenson, 2003) to be significant in determining the establishment of local biotechnology firms. Owen-Smith and Powell note that the field of biotechnology “had its origins in university labs, where research was supported by decades of substantial government investment in R&D” (2004: 8). The importance of universities as a source of research and human capital is acknowledged in the literature, but there has been little study of the establishment of biotechnology-related university departments or programs.

This paper studies bioengineering departments, a population of university departments that is closely related to the biotechnology industry. Bioengineering is a broad term that includes both biological and biomedical engineering. Though studies of biotechnology firm foundings have considered reasons for the emergence of biotechnology firms in particular locations, the question that this paper addresses is not focused on specific locations or subpopulations. Instead, this paper addresses the questions of how bioengineering departments emerged as a population and why the founding rate of the population exhibits a certain pattern.

Organizational ecology is a useful framework for studying the population of bioengineering departments. Organizational ecology is a strand of literature within organizational theory that shifts the level of analysis from individual organizations to a population of organizations. This shift is a result of the observation that individual organizations are subject to strong inertia that constrains their ability to change or adapt. Organizational ecologists suggest that the organizational environment selects individual organizations.

Population ecology was launched with the question, "Why are there so many kinds of organizations?" (Hannan and Freeman, 1977). Most of the research that has been conducted since this time has focused on a slightly different question, "Why does the number of organizations of a given kind vary over time?" (Carroll and Swaminathan, 1991; Carroll et al, 1993). Population ecologists have studied how and why populations of organizations emerge, change, and decline by studying vital rates: rates of founding, growth, and failure. The main interest is how these rates are influenced by intra-population dynamics and environmental conditions.

Organizational ecologists have drawn on institutional theory, which has a broader conception of organizational environment, to expand population ecology theory and research. The theory of density dependence is at the root of the use of institutional insights in ecological work, and has remained central to population ecology research. Population ecology research continues to use and test the theory of density dependence, and the theory has been expanded, as empirical studies show weaknesses of the theory's predictions. In particular, population ecology theorists have sought to modify and add to density dependence models in relation to mature populations. Mature organizational populations often exhibit patterns of growth and decline after the initial peak predicted by density dependence. This has led to theories of mass dependence, density delay, and temporal heterogeneity.

Density dependence theory has been expanded by the prediction that processes of competition and legitimation differ by geographic level. Researchers study the effects of legitimation and competition processes at different geographic levels of a population. Density dependence research has divided populations of organizations into sub-populations in order to study the effect of institutional variables that differ by political boundaries.

In addition to studying the intra-population density dynamics of one population – either vertically, at different levels of geographic aggregation, or horizontally, by comparing localities – density dependence theory has expanded by considering inter-population density dynamics. The premise is that populations of organizations may be distinct populations in terms of resource space and organizational form, but functionally complementary. Interpopulation dependence is often studied in relation to high-tech industries that share a technological and knowledge base.

The biotechnology industry is one that is characterized by a high level of interpopulation dependence. Bioengineering departments are an important population within this community, but one that has not received much attention. This paper intends to address this gap. The emergence and growth of the bioengineering department population is studied, first, in relation to the intra-population dynamics of legitimacy and competition through density dependence theory. The paper also considers an alternative explanation for the growth of bioengineering departments. The alternative explanation predicts that the universities that establish bioengineering departments are engaged in strategic interaction that has a significant effect on the pattern of adoption of departments. The hope is that study of the effect of intra-population dynamics and institutional environment on the founding rate of bioengineering departments will provide a basis for further study of interactions within the population of bioengineering departments as well as interactions between the population of bioengineering departments and other actors in the field of biotechnology.

CHAPTER 2

ORGANIZATIONAL ECOLOGY LITERATURE

2.1 Foundation for Population Ecology Research

Hannan and Freeman (1977) established a framework for the population ecology research agenda with a seminal work that argued for an ecological approach to understanding the effects of organizational environment. Ecological research is characterized by its focus on selection processes. Hannan and Freeman (1977) argued that organization theory was overly focused on the adaptation of individual organizations. They do not claim that individual adaptation does not take place. Rather, they suggest that internal and external constraints limit individual organizational adaptation, and hypothesize that organizational variability is a result of competition and selection.

Hannan and Freeman's reasoning about environmental selection entails not only a shift from an adaptation to a selection perspective, but it also entails a shift in unit of analysis from an individual organization and its environment to a population of organizations and a shared environment. In defining population, Hannan and Freeman begin with the idea that a population is characterized by organizations that respond similarly to changes in the environment, or, that "are relatively homogenous in terms of environmental vulnerability" (1977: 934). They expand upon this definition to include the concept of organizational form, which relates to a common blueprint for action, a framework that structures how organizations receive, process, and act upon information.

The focus on selection and the shift to the population-level unit of analysis have a purpose, and as Hannan and Freeman explain, this purpose is to “understand the distributions of organizations across environmental conditions and the limitations on organizational structures in different environments” (1977: 936). To look at the relationship between distribution of organizations and environments, they emphasize the importance of isomorphism and competition.

Isomorphism is the observation that organizations facing the same constraints will resemble each other in structure and strategy. Within population ecology, there is an important assumption that isomorphism is a result of environmental selection – it is the environment that determines organizational form and distribution. Environmental selection works through the process of competition for scarce resources. As Hannan and Freeman write, “organizational forms presumably fail to flourish in certain environments because other forms successfully compete with them for essential resources” (1977: 940).

Population ecology is a term that is often confused with the broader term organizational ecology, which is simply the application of an ecological approach to the study of organizational populations (Carroll, 1984; Nunez-Nickel and Moyano-Fuentes, 2006). Population ecology is one of three levels of analysis within organizational ecology, the others being organizational demography and community ecology. Population ecology is distinguished from the other levels both by its selection approach and by its interest in the growth and decline of populations of organizations. Population ecology also includes the study of interactions between populations of organizations. All three levels of research within organizational ecology examine the vital rates of organizational populations: foundings, growth and decline, and deaths. Carroll explains that population ecology research differs from organizational demography when "an independent variable interacts organizational form with environmental condition" (1984: 85). Community ecology retains the interest in organizational form and studies the emergence and disappearance of forms rather than of specific populations.

Both theoretical and empirical organizational ecology research has been conducted at all three levels, which has resulted in a large amount of literature. This literature review will give a broad overview of much of the literature, with a specific focus on the research that has analyzed founding rates in organizational populations.

2.2 Early Population Ecology Research

Early work within population ecology focuses on the study of structural inertia, organizational niches, and resource partitioning. Hannan and Freeman (1984) build on their earlier work by studying inertial force in greater depth, questioning the strength of inertial forces on organizational structure. They relate the concept of structural inertia to vital rates within populations, arguing that selection favors organizations whose structures have high structural inertia, structural inertia increases with age, organizational death rates increase with age, attempts at reorganization increase death rates, and complexity increases the risk of death due to reorganization (Hannan and Freeman, 1984).

Freeman and Hannan (1983) also extend their work by studying organizational niches in more detail. An organizational niche is a resource space that supports a specific population. The concept of niche width is defined as "a population's tolerance for changing levels of resources, its ability to resist competitors, and its response to other factors that inhibit growth" (Freeman and Hannan, 1983: 1118). Though the concept of niche width is introduced in their earlier work, Freeman and Hannan (1983) predict the effect of niche width on failure rates of organizational populations. The level of environmental variability and the pattern (or, grain) of variability determine niche width. Course-grained niches are characterized by less frequent variability than are fine-grained niches. Freeman and Hannan (1983) find evidence that niche width affects failure rates within organizational populations, and that through this effect, niche width has an effect on the relative distribution of specialist and generalist organizations within a population.

Niche width became a significant area of research in early population ecology literature. The initial focus of this research was on the distribution of specialist and generalist organizations within a population (Carroll, 1985), but the concept of niche also became an important method of conceptualizing heterogeneity within population. The study of organizational niches also provided a unique method for studying of two types of interdependence, competition and mutualism, within an organizational population (Baum and Singh, 1994).

An early study by Delacroix and Carroll (1983) has shaped the study of founding rates within organizational ecology. They note that until that point, study of founding rates had largely been avoided within organizational ecology studies due to the impossibility of defining the risk set at an individual level. Analysis of failure rates is able to consider an individual organization as the unit of analysis (though the population remains the *level* of analysis), but analysis of founding rates must use the population as both the level and unit of analysis. This restricts the amount of information that can be used in the analysis of founding rates; in sum, "since there is not organization prior to founding, organizational attributes cannot be used as independent variables" (Delacroix and Carroll, 1983: 275). They suggest the use of a level of environment to define a population as the unit of analysis; possible levels include neighborhood, region, or nation-state. This method of analyzing the population initially expanded the study of founding rates, and later inspired research that has sought to address the disadvantage of population-level analysis, which is the implicit assumption that organizations within the population are homogenous.

In a study of populations of newspapers in Argentina and Ireland, Delacroix and Carroll (1983) model the effects of both intra-population dynamics and institutional environmental variables on the founding rate of newspapers. They include ecological variables in their analysis by relating prior organizational births and deaths in the population to current births. They expect the effect of both prior births and prior deaths to be curvilinear and the combination of the effects to generate a cyclical process of organizational births. They also consider several socio-political environmental factors in their analysis, including political turbulence, election year, economic prosperity, and business cycles. They find the expected relationship between prior births and deaths to be curvilinear as expected, but find political turbulence to be the best predictor of current newspaper foundings.

Thus, this study (Delacroix and Carroll, 1983) was important both because it prompted study of organizational foundings at the population level, but also because it identified important population-level variables to be used in such analysis.

2.3 Early Critiques of Population Ecology

Early criticism of population ecology research focused on “the supposedly deterministic nature of ecological ideas, the lack of attention to adaptation and change,

[and] the nature of the key constructs and the units of study" (Singh and Lumsden, 1990: 184). These criticisms and the responses of population ecologists are a fitting transition between early research, which establishes the fundamental approach and concepts used in population ecology, and the subsequent stage of research, which emphasizes the convergence of population ecology and institutional theory.

The first two criticisms are closely related. Criticism that population ecology research is deterministic is based on claims that population ecology ignores the role of managers within organizations and dismisses adaptive decisions and learning of individual organizations (Astley and Van de Ven, 1983). As noted earlier, in their article on population ecology, Hannan and Freeman (1977) do not deny that adaptation takes place or that individual leaders within organizations can affect organizational outcomes, they simply claim that selection is the stronger process, and that it warrants study by organizational theorists.

Young (1988) takes issue with the constructs used in population ecology research, and this criticism is the third and final critique to be considered in relation to early ecological research. Young makes the following claims about population ecology:

> concepts developed for biology are often difficult to apply to organizations, reasoning is sometimes questionable, new hypotheses developed for organizations do not seem to be derived or to benefit form biological theory, and empirical support is lacking (1988: 1).

Most of these claims are related to the relationship between organizational ecology and its biological ecology antecedent. Organizational ecologists respond to Young's critique by claiming that she is too literal (Brittain and Wholey, 1989; Freeman and Hannan, 1989). Freeman and Hannan emphasize that Young's critique "takes as its premise the incorrect view that we have attempted to reduce organizational processes to biological ones, that we seek a mapping between organizational and biotic worlds" (1989: 426). Similarly, Brittain and Wholey claim that "Young's criticisms of ecological theory unravel when the theory is evaluated in sociological rather than biological terms" (1989: 440).

2.4 Density Dependence

A significant development in organizational ecology research is the use of population density as variable of interest in studying the effect of intra-population ecological dynamics on vital rates of the population. Though density has been used to model dynamics such as competition and mutualism (Barnett and Carroll, 1987), it has been most extensively applied through the model of density dependence.

The model of density dependence predicts that the relationship between the number of organizations in a population (population density) and the rate of founding of new organizations in the population is non-monotonic. The non-monotonic relationship is explained in terms of legitimacy and competition. At low levels of density, founding rates rise as population density increases because each additional organization increases the legitimacy, or the "taken-for-grantedness", of the population (Hannan and Freeman, 1987). As population density continues to increase, the need for legitimacy declines, and competition becomes the dominant process. At high levels of density, resources are expected to be scarce and competition for these scarce resources has a negative effect on the founding rate of organizations in the population (Hannan and Freeman, 1987; Carroll and Hannan, 1989).

The density dependence model also makes predictions about the effect of population density on morality rates. Morality rates are expected to be low when population density is low and resources are abundant; they are expected to be high when population density is high and resources are scarce (Carroll and Hannan, 1989). Early empirical work by Carroll and Hannan (1989) found the predictions about founding rates to hold in relation to founding rates in populations of newspapers, but the predictions about failure rates only held in large populations.

There is large body of work that has been devoted to testing the predictions of density dependence in various populations of organizations. Before considering the results of these studies, it is important to review in more depth the meanings of legitimacy and competition that are used in relation to density dependence.

Hannan and Carroll (1992) explain that the theory of density dependence is unique not in its conception of legitimacy or competition, but in its combination of assumptions about legitimacy and competition with population density. Direct measures of competition and legitimacy are often unavailable; density dependence theory suggests that at a general level, population density is a useful proxy for these processes as it is a driver of both competition and legitimacy in organizational populations. Hannan and Carroll (1992) emphasize that density is not an indicator in the sense that it reflects the processes of competition and legitimacy; rather, they argue that density is an indicator because, in a more direct sense, density controls the processes of competition and legitimacy.

Density dependence theory draws assumptions about the nature of competition within an organizational population from human ecology, in which competition is assumed to be diffuse and indirect (Hawley, 1944). Competition is a process by which organizations compete for similar resources; it is assumed to be indirect because the process or dynamic exists regardless of whether organizations are aware of the number or identity of the other organizations that occupy the same resource space (Hannan and Carroll, 1992). This conception of competition is based on the assumption that a finite carrying capacity exists for the population and is set by environmental conditions. Density is assumed to be positively related to diffuse competition; competition will become more intense as the number of organizations in a population increases and seeks to draw from the same finite resource space. As competition increases, founding rates are expected to decline.

Density dependence theory emphasizes legitimacy as a norm-based state of taken-for-grantedness (Meyer and Rowan, 1977; Meyer and Scott, 1983) over an understanding of legitimacy as coercive institutional isomorphism (DiMaggio and Powell, 1983), which is based on legality or rules. The understanding of legitimacy as taken-for-grantedness is referred to as constitutive legitimacy (Carroll and Hannan, 2000). This conception of legitimacy is taken from institutional theory, and represents the beginning of efforts to use insights from institutional theory in ecological research. It is important to distinguish this use of theoretical concepts (especially in relation to legitimacy) derived from institutional theory from the use of institutional environmental variables, such as political turbulence, which had been used in ecological research (Delacroix and Carroll, 1983; Carroll and Huo, 1986) before the development of the density dependence model.

Density is assumed to be positively related to legitimacy; as the number of organizations in a population increases, each additional organization is assumed to contribute to constitutive legitimacy. There is a point, however, when legitimacy reaches a ceiling, the population is perceived as natural, and an additional organization does not add to the population's legitimacy. Founding rates are expected to rise with legitimacy.

The assumption that there is a fixed ceiling of constitutive legitimacy simplifies the expectation of the combined effect of competition and legitimacy on founding rates. Legitimacy is expected to have a stronger effect on founding rates at lower levels of density. Density dependence predicts that a population's founding rate rises with legitimacy up to a certain point, at which the competition process becomes the stronger force. After this point, further increases in population density are expected to have a negative effect on founding rates.

The theory of density dependence has been applied to a wide range of organizational populations, and the majority of studies have found the predicted density relationship to be significant for both founding and mortality rates (Singh and Lumsden, 1990; Carroll and Hannan, 2000). Density dependence has been studied in the following populations, among others: automobile manufacturing (Hannan et al, 1995; Rao, 1994), beer brewing (Carroll et al, 1993), banks (Lomi, 2000), newspapers (Carroll and Hannan, 1989), day care centers (Baum and Singh, 1994), hotels (Baum and Mezias, 1992; Ingram and Inman, 1996), and labor unions (Hannan and Freeman, 1989).

In 1995, Baum and Powell examined density dependence articles that had been published in the previous five years and found that there is stronger support for density dependence predictions in relation to founding rates than in relation to failure rates. They also found that support for density dependence is stronger in populations that have just passed their peak density than in populations in which information for a longer period of time is available and which have experienced decline after the density peaks (Baum and Powell, 1995).

Over time, more evidence has emerged that density dependence predictions do not hold as well in mature populations (Ruef, 2004; Lomi et al, 2005). Density dependence predicts population dynamics well until the point after which the population has reached its peak density. The evolution of organizational populations after this peak has become a new area of research for organizational ecology (Carroll, 1997; Carroll and Hannan, 2000).

Early efforts to develop a model to explain post-peak dynamics include mass dependence (Barnett and Amburgey, 1990) and density delay (Carroll and Hannan, 1989). Density delay (Carroll and Hannan, 1989) predicts that the density of the population the year that an organization is born affects its probability of failure rate; organizations that are born in years when density is high face a more competitive environment at the time of founding, and thus, are expected to have a higher risk of failure. This model relates only to growth and failure rates; it does not make predictions about founding rates. Mass dependence (Barnett and Amburgey, 1990) makes predictions about founding and failure rates in an organizational population on the basis of population mass rather than population density. This model takes into account the possibility that larger organizations have a stronger (positive) effect the level of competition within a population than do smaller organizations. The model predicts that as mass increases, founding rates fall and failure rates rise.

More recent efforts to explain post-peak dynamics include temporal heterogeneity (Hannan, 1997) and community dependence (Ruef, 2004; Lomi et al, 2005). Hannan

(1997) introduced the model of temporal heterogeneity, which predicts that the expected effects of legitimacy and competition depend not on population density, but on the interaction of population density and population age. The effects of both legitimacy and competition are expected to become less sensitive to density as the population ages. This model has been primarily applied to founding rates of organizational populations (Barron, 2001; Dobrev, 2001; Wezel, 2005).

Community ecology is an approach that emphasizes inter-population dynamics, and suggests that vital rates depend not only on intra-population dynamics but also on inter-population dynamics. Ruef claims that certain populations are best understood not in isolation but “in the context of a concrete system of interrelationships between organizational suppliers, consumers, regulators, and intermediaries” (2000: 660). There has been little empirical research in the area of community dynamics and relations between organizational populations, especially in relation to founding rates.

Audia et al note that “the few studies that have examined the impact of multiple organizational populations on entrepreneurial activity have tended to focus on a small subset of populations that researchers assume a priori to be particularly influential” (2006). They cite studies by Zucker et al (1998) and Stuart and Sorenson (2003) as examples of research that has considered inter-population dynamics but that are limited by the focus on a small subset of populations. Audia et al (2006) combine an ecological approach that is focused on inter-population dynamics with network analysis to analyze the founding rates of instrument manufacturers in the United States. They find that foundings increase as the density of populations that have symbiotic and commensalistic relations with the population of instrument manufacturers increases. This is similar to

Baum and Oliver's (1992, 1996) study of institutional embeddedness, which will be discussed in further detail in the following section on the convergence of ecology and institutionalism.

Lomi et al (2005) introduce the concept of system-dependence. System dependence assumes that populations of organizations are able to influence their environment and, further, that their ability to influence the environment increases as the population ages. They argue that environments of organizational populations are endogenous and that resource constraints are dynamic. Dynamic resource constraints introduce the possibility that populations can overshoot the carrying capacity of the environment if there are delays in the response of organizational vital rates to changes in resource levels. Lomi et al (2005) present this model as an explanation for post-peak fluctuation in mature organizational populations, but do not test it empirically.

This section of the literature review has focused on the theory of density dependence. Density dependence is an important model within organizational ecology, especially in explaining intra-population dynamics in young populations. Empirical research has shown density dependence to be less accurate in relation to mature organizational populations. Rather than negating research on density dependence, these empirical findings have inspired further work to expand the model of density dependence. This has led to theories of density delay, mass dependence, temporal heterogeneity, community dependence, and system dependence. The next section of the literature review considers a different aspect of density dependence research; namely, its relation to institutional organization theory.

2.5 Interaction of Ecological and Institutional Dynamics

Early articles that develop the theory of density dependence present the theory as a convergence of institutional and ecological perspectives. In one of these early articles, Carroll and Hannan claim that their study of the density dependent processes of legitimation and competition "can be seen at a more general level as a synthesis of theoretical perspectives commonly held to be in opposition to each other" (1989: 525).

Institutionalism, like organizational ecology, focuses on the importance of organizational environment, but has a broader and more detailed conception of what composes the environment. Research in organizational ecology tends to focus on resources and the competition for resources as the fundamental characteristics of organizational environments, whereas "institutional theorists broadened the framework to comprehend the role of regulative, normative, and cultural forces working to constrain and constitute organizations, organizational populations, and organizational fields" (Scott and Davis, 2006: 258). A widely cited definition of institutions describes them as being "composed of cultural-cognitive, normative, and regulative elements that, together with associated activities and resources, provide stability and meaning to social life" (Scott, 2001: 48).

Density dependence theory draws on institutional theory that focuses on the cultural-cognitive aspects of institutions. Density dependence theory's conception of legitimacy is derived specifically from Meyer (1983) and Meyer and Rowan's (1977) conception of legitimacy as taken-for-grantedness (Hannan and Carroll, 1992). This understanding of legitimacy central to the cultural-cognitive conception of institutions, in which the basis of legitimacy is that it is comprehensible, recognizable, and culturally supported (Scott and Davis, 2006: 259).

Zucker (1989) critiques population ecologists' use of cognitive-cultural legitimacy in density dependence theory. She criticizes the theory of density dependence for not directly measuring legitimacy and competition. She argues that there is insufficient evidence of a link between density and the processes of legitimacy and competition. She also suggests that the non-monotonic form is not necessarily a function of legitimacy or competition, but could be the result of an exogenous shock, such as "new inventions or major scientific discoveries" or "political and/or social changes" (Zucker, 1989: 543).

Baum and Oliver (1992) respond to Zucker's critique that there should be more direct measures of institutional processes by introducing the concept of relational density. Relational density is introduced as a proxy for embeddedness in the institutional environment. They study a population of day care centers, and measure relational density as the number of purchase-of-service agreements (direct relationship with government) and the number of site-sharing arrangements (connectedness with social institutions). They predict that relational density is the source of the non-monotonic form. They study founding and failure rates and find evidence to support their predictions; when relational density is included as a variable, the legitimating effects of increases in population density are no longer significant, but competitive effects remain significant.

In comment on Hannan et al (1995), Baum and Powell (1995) make a further criticism of population ecology's use of the concept of legitimacy. They argue that Hannan et al (1995) treat density as a process when they feel that it is better understood as a proxy for relational or cognitive density. They also criticize Hannan et al (1995) for exclusive emphasis on cognitive dimension of legitimacy to exclusion of socio-political legitimacy.

Hannan and Carroll (1995) respond to this criticism, claiming to use both kinds of estimates (cognitive and socio-political) but to give greater emphasis to cognitive legitimacy. Their first reason for emphasizing cognitive legitimacy is because they consider the use of socio-political legitimacy variables to be "restat[ing] the obvious" (Hannan and Carroll, 1995: 540). The second reason they give for emphasizing cognitive legitimacy is methodological. They argue that institutionalists treat changes in the institutional environment as exogenous, when "dynamics of the organizational population frequently affect the timing and form of legislation and regulation" (540). The idea that population dynamics can result in institutional change is an approach to joining institutional and ecological perspectives, but it is an approach that is used much less than the study of how institutional variables affect vital rates of organizational populations (Singh and Lumsden, 1990).

Research concerning the convergence of institutionalism and population ecology has continued to expand, mostly through the inclusion of variables that capture effects of institutional environment. Institutional environment is often studied in relation to the effect of institutions on legitimation and competition processes in populations. Density dependence is part of this line of research, as is work on institutional embeddedness. Baum and Oliver (1992) argue that institutional embeddedness, which they measure by relational density, confers legitimacy and resources. In later work, Baum and Singh (1994) and Baum and Oliver (1996) expand their work to consider competitive dynamics within populations by introducing the concept of overlap density and non-overlap density. Baum and Oliver (1996) build on their institutional embeddedness research by drawing on the concept of organizational niche, and expanding it to include differences in competitive orientation and social legitimacy of organizations within the same population. Though Baum and Oliver's work began by considering institutional effects related to density, it expanded to the study of competition dynamics as well. This trend is characteristic of the progression of research on the convergence of institutionalism and population ecology.

Russo (2001) classifies research on institutional effects on competitive interactions into three categories: direct channeling of resources to organizations through policy making, ties between organizations and key institutions, and policy that constrains where and how organizations can compete. Effects of embeddedness have already been discussed. Direct channeling of resources occurs through favorable tax policies (Swaminathan, 1995), government subsidies (Tucker et al, 1990), and public capitalization (Dobbin and Dowd, 1997). Differences in regulative policy across states or regions (Carroll and Wade, 1991; Lomi, 1995; Wade et al, 1998) are a common area of study in relation to the effects of policy on determining where and how organizations compete. Dobbin and Dowd (1997) study direct competition policies, such as pro-cartel or anti-trust policies, and the effect on railroad foundings. Pro-cartel policies were found to increase foundings, while antitrust policies decreased foundings by raising the level of competition.

The research on institutional effects on competitive interactions stays within organizational ecology's use of the concept of competition to refer to indirect and diffuse competition. This understanding of competition emphasizes that organizations compete because they require the same resources. It does not consider the possibility that organizations may compete directly, which could involve each organization basing decisions on the actions of others organizations in the same population. These assumptions about the nature of competition between the organizations influence the type of policy that is expected to influence organizational populations: namely, policy that affects either the number of organizations allowed in a population (pro-cartel, anti-trust) and policy that affects the level or distribution of resources.

CHAPTER 3

HISTORY OF BIOENGINEERING

3.1 Development of Biotechnology Industry

Biotechnology is an industrial sector that has its beginnings in Watson and Crick's work on DNA structure in the early 1950s. The industry expanded with the development of new knowledge in fields such as biochemistry and cell biology. Owen-Smith and Powell claim that the industry "had its origin in university labs" and that it remains highly dependent on research conducted by public research organizations (2004: 8). Biotechnology is also characterized by fairly small firms that conduct high levels of research and development. The actual work of biotechnology deals with the application of biological knowledge to molecular, cellular, and genetic processes; the design of new compounds; and the development of biological products and services (Malerba and Orsenigo, 2002; Cortright and Mayer, 2002).

The academic discipline of bioengineering is relevant to biotechnology industry, as well as to pharmaceutical, medical device and implant, and tissue engineering industries. Bioengineering is defined as the application of engineering principles and methods to biology and human health. Research within bioengineering has primarily focused on biomedical engineering and medical applications, but agricultural and environmental research areas are also considered to be bioengineering.

One way that bioengineering research contributes to biotechnology is through the development of new processes for manufacturing; an example is the manufacturing of human insulin, "the first product based on recombinant DNA technology, where bioengineering was critical to the ability to commercialize the product" (National Institutes of Health, 1993).

3.2 Emergence of Bioengineering Departments

The academic field of bioengineering has its roots in the expansion of biological knowledge and research of the 1950s. Education and research programs in bioengineering began to be formed in the 1960s, and the first bioengineering departments in the United States were established in the early 1970s.

University research in the area of bioengineering was conducted as early as the late 1940s at the University of Pennsylvania. The first programs in bioengineering were established in the 1950s at four universities: University of California at Berkeley and San Francisco, University of Pennsylvania, Iowa State University, and Drexel University. The term "biomedical engineering" was established in the late 1960s. Before this term was established, research in this area was described as "medical electronics" or "engineering in medicine and biology" (Nebeker, 2002). The term "bioengineering" also emerged in the late 1960s but was not commonly used at that time. Bioengineering is now understood to be a broader term that includes biomedical engineering as well as other bio-focused engineering areas.

The number of bioengineering programs grew from 40 programs in 1965 to 180 in 1971. The first two bioengineering departments were established in 1968, at Case Western University and the University of Virginia. Four more departments were established in 1970. The growth of bioengineering departments over time is shown in Figure 3.1.

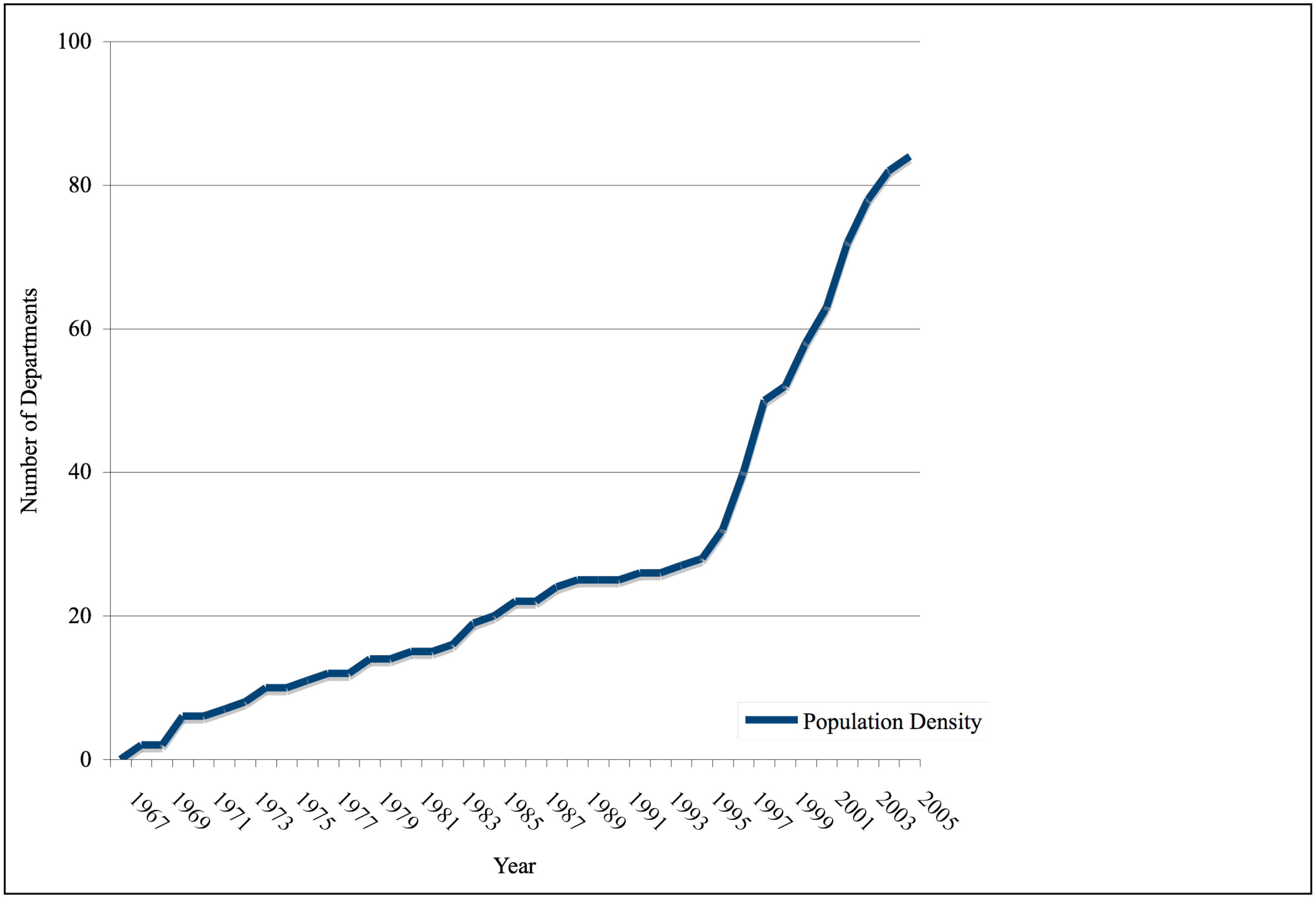

Figure 3.1 Population Density of Bioengineering Departments: 1967 to 2005

The Whitaker Foundation, a private sponsor of bioengineering research and education, was established in 1975. For the first few decades of its existence, the Whitaker Foundation "spent about 10% of its capital annually (about $14 million) mostly in 3-to-4 year grants to young faculty members" (Grimm, 2006). In 1991, the board of the Whitaker Foundation decided to spend out the entire endowment, as the U.A. Whitaker had not intended the foundation to last more than 40 years, and "because the board wanted to increase the impact of the foundation when the field was at the cusp of becoming mainstream" (Grimm, 2006). In addition to providing grants to individuals for research, the Whitaker Foundation began to award universities grants to establish bioengineering departments.

In an article about the emergence of bioengineering departments, Robert Nerem, chair of the Bioengineering Department at the Georgia Institute of Technology makes the following argument about the impact of the Whitaker Foundation on the emergence of bioengineering departments:

> Why are these new initiatives appearing? Some say a major factor is the Whitaker Foundation, located in Arlington, Virginia, and dedicated to the support of biomedical engineering. However, what these institutions are doing is responding to student interest, to the emergence of new industries, and to the exciting new engineering problems posed by developments in biology. The support of the Whitaker Foundation has been and will continue to be important; however, these institutions are investing resources of their own, which in many cases are far in excess of the support they are receiving from external sources (1997).

This argument is interesting because it claims that though the Whitaker Foundation had an impact on the emergence of bioengineering departments, there were less direct elements of the institutional environment that were as important as support by the Whitaker Foundation.

3.3 Changes in Institutional Environment of Bioengineering Departments

There are two important institutional changes to consider in relation to the environment of bioengineering departments: first, the increasing government support for university biomedical research through the National Institutes of Health and, second, an increasing trend of university commercialization of research.

National Institutes of Health (NIH) funding has grown over the decades with increasing public concern about health care. During the 1950s, appropriations for the NIH "increased from $52 million to $430 million" (Nebeker, 2002). More recently, the NIH budget doubled between 1998 and 2003. During the 1960s, the NIH introduced a program to promote the introduction of engineering into biomedical research, and created training programs and a research base for biomedical engineering. The NIH did not have an institute or center devoted to bioengineering until 2001, however. In 1993, an External Consultants Committee produced a report for the NIH, recommending that the NIH establish a central focus for biomedical engineering, increase bioengineering presence on peer review committees, and establish new research programs targeted at bioengineering research. The NIH did not establish a central focus for biomedical engineering until December 2000, when the National Institute of Biomedical Imaging and Bioengineering (NIBIB) was established.

In the early 1980s, there was a policy effort in the United States to increase patenting and commercialization activity by universities in order to increase university contributions to economic growth. The Bayh-Dole Act, which was passed in 1980, formalized university intellectual property rights by introducing standard rules for the ownership of academic intellectual property that had been generated with federal research support (Owen-Smith, 2003). Policy to encourage technology diffusion is especially relevant to engineering disciplines like bioengineering, which we have already seen has extensive industrial applications.

CHAPTER 4

ANALYSIS OF BIOENGINEERING DEPARTMENT FOUNDING

4.1 Research Question and Hypotheses

The research question and hypotheses presented in this section are motivated by the convergence of ecological and institutional research. The institutional factors considered in the analysis are motivated by the history of the emergence of bioengineering departments. The questions this analysis will address are: Are ecological dynamics, specifically density dependence, significant in explaining founding rates in bioengineering departments in the United States? And, if they are significant, do they remain significant when institutional variables have been included in the model?

Ecological Effects on Founding

Hypothesis 1: Population density has a non-monotonic effect on founding rates of bioengineering departments; the first order effect of density is expected to be positive, and the second order effect is expected to be negative.

Hypothesis 1 is based on the theory of density dependence, which predicts that density drives processes of legitimation and competition. Legitimacy rises with the number of organizations in a population and encourages foundings. Due to resource constraints, at a certain point competition will become the dominant process within the population. At this point, competition rises with the number of organizations in the population and discourages foundings.

The theory of density dependence has been extended to consider density at different geographic levels, based on the assumption that legitimacy and competition processes are localized in certain populations. This does not seem to be the case in relation to university departments, as departments compete for national level federal funding, and are more likely to be members of national associations (for example, the American Institute for Medical and Biomedical Engineering) than state associations.

Density dependence theory has also been expanded to address cycles that have been observed in mature organizational populations after the density-dependent peak has been passed. These theories, such as mass dependence and density delay, are more applicable to mature populations. The population of bioengineering departments is young; therefore, I do not consider more complex models of density dependence.

Resource Effects on Founding

Increases in resources are expected to have a positive effect on founding rates within populations of organizations. I test the effects of two different types of funding, both of which are expected to be significant in encouraging founding rates of bioengineering departments.

Hypothesis 2: Private funding from the Whitaker Foundation has a positive effect on the founding rate of bioengineering departments.

Hypothesis 3: Increases in government support for bioengineering research has a positive effect on the founding rate of bioengineering departments.

Regulatory Policy Effects on Founding

I consider policy that encourages university commercialization to be a type of regulatory institution; standardizing rules for competition in the academic market should increase the founding rate of departments that engage in research that can be transferred to industry and patented.

Hypothesis 4: Policy that encourages universities to engage in commercialization, especially in the area of science and engineering, will have a positive effect on the founding rate of bioengineering departments.

Hypothesis 4 predicts that a policy that focuses on commercialization will impact in academic disciplines engaged in research with potential for industrial application, such as biotechnology. Commercialization policy is expected to have encouraged the growth of the bioengineering discipline, which resulted in formation of departments because this is the conventional organizational form within universities.

4.2 Methods and Model

Sample

While population ecology research uses a variety of models to study the vital rates of organizational populations, there are two unifying methods of population ecology research. First, as the name suggests, population ecology research studies an entire population of organizations rather than a sample or sub-set of a population. Second, population ecology research follows the entire history of the organizational population. Exclusion of data on the formative years is problematic, especially in relation to density dependence theory, as strong effects of density are predicted during these years.

Based on history of bioengineering departments, it is apparent that there was a higher rate of foundings of programs, and that programs were also founded more quickly than departments. There is a reason that this paper focuses on departments rather than programs, and why it does not consider them to be part of the same population. Population ecology is applied to organizations, and, even if it could be argued that degree programs are organizations, programs do not have the same level of structural inertia that is characteristic of university departments. Programs are administered by faculty members in multiple departments, and are much less structured than departments. Population ecology is applied to organizations, and is most relevant to those that exhibit structural inertia.

I limit my study of bioengineering departments to a study of the founding rates. At this point, there is no evidence of failures within the bioengineering department population. There two possible reasons for the lack of failure: the young age of the population and the stability of university departments as organizations. In the only population ecology study that I have found related to universities, Ruef (2004) studies medical schools and does find a high number of failures. Medical schools can be considered quite different in form than bioengineering departments, though both are academic institutions. If a bioengineering department were to fail, it would be more likely to "fail" through name change or merger.

I test the hypotheses using times series data on the founding of biotechnology departments. I model only the founding rates for the years 1967 through 2005.

Dependent Variable

Department Foundings. The dependent variable of interest is the number of foundings of bioengineering departments per year. I collected data on the founding year of each department in the population of 84 bioengineering departments from the Whitaker Foundation Curriculum database.

Independent Variables

Population Density. Population density is calculated as the total number of bioengineering departments that exist per year. There are no failures in the population of bioengineering departments; thus, population density is a function of the number of prior births.

Population Age. Population age is number of years since the first bioengineering department was founded. Population age is added as a control variable, in order to control for the possibility that density-dependence is a simply a reflection of progression of time. Cattani et al explain that population ageing could have a negative effect on founding rates: “a Darwinian perspective on evolution… assumes that it is more difficult to enter a mature than a young population” (2003: 673).

Whitaker Foundation Funding. Whitaker Funding is the total amount of money awarded through grants by the Whitaker Foundation by year between 1975 and 2005. Data on amount awarded by grant type (for example, to distinguish between grants for research and grants for founding departments) was not available for the complete time period; therefore, I use the aggregate amount. The Whitaker Foundation was established in 1975; therefore, the amount of funding per year before 1975 is zero. The source for total funding by year is a chart published in a 2006 *Science* article (Grimm).

Government Funding. I measure government funding by the yearly amount of National Institutes of Health funding that is allocated to "not elsewhere classified" engineering research. "Not elsewhere classified" is a category that captures engineering research supported by the NIH that does not fall into the following seven categories: aeronautical engineering, astronautical engineering, chemical, civil, electrical, mechanical, and metallurgy & materials. It is reasonable to assume that bioengineering captures the research that is not included in the above categories. Furthermore, the values for amount of support for the seven specified categories are all zero for the duration of the data.

I obtained the data from a National Science Foundation (NSF) report on Federal Obligations for Research by Agency and Detailed Field of Science and Engineering between 1970 and 2002. The data range presented a problem because it does not quite cover the later years in the study. For the later years in the study, I obtained data on the yearly appropriation for the NIBIB, which was established in 2001.

I use data from the NIH to proxy the level of government resources available to bioengineering department because is the institute that has contributed the majority of federal research grants to the field of bioengineering (AIMBE, 2006). I lag the level of NIH funding, assuming that there is a perception delay.

Commercialization Policy. To study the effects of US policy encouraging university commercialization, I include a dummy variable for the Bayh-Dole Act. The dummy variable is equal to 0 before the act was passed in 1980 and equal to 1 in 1980 and after.

Model Specification

Because the dependent variable in this analysis is a count variable, I use a Poisson regression model. The Poisson model assumes that the mean of the expected event counts equals the mean. If this is not the case, the data is described as exhibiting overdispersion (the variance is significantly greater than mean), and a negative binomial model is preferred to Poisson. I test for overdispersion, and not finding significant evidence of overdispersion in the data, I use the Poisson model, which gives smaller standard errors.

Density dependence research specifies the following founding rate model:

$$\lambda(t) = l_t N_t^{\alpha} \exp(\beta N_t^2),$$

where l_t summarizes the effects of variables other than density on the founding rate at time, t.

4.3. Results

Table 4.1 presents descriptive statistics for variables used in the Poisson analysis of founding rates.

Table 4.1 Descriptive Statistics for Founding Analysis

Variable	Mean	Std. Dev.	Density	Population Age	Whitaker Funding	NIH Funding	Bayh-Dole
Density	27.18	23.14	1.00				
Population Age	20.0	11.40	0.91	1.00			
Whitaker Funding	23.15	25.76	0.94	0.93	1.00		
NIH Funding	88.11	89.12	0.87	0.83	0.89	1.00	
Bayh-Dole	0.64	0.49	0.62	0.83	0.66	0.57	1.00

Table 4.2 shows Poisson models of the founding of bioengineering departments. Model 1 is the baseline model. It includes the density dependence variables and the control for population age. Model 1 shows support for Hypothesis 1 (Density Dependence). Density has a significantly positive first-order effect on foundings. The second-order effect of density is smaller than the first-order effect, but is negative, as the density dependence model predicts. Population age is also shown to be significant in this model, and to have a negative effect on foundings.

Table 4.2 Poisson Analysis of Bioengineering Department Founding

	Model			
Variable	(1)	(2)	(3)	(4)
Density	0.274	0.179	0.163	0.168
	(0.061)**	(0.066)**	(0.067)*	(0.068)*
$Density^2$	-0.002	-0.001	-0.001	-0.001
	(0.000)**	(0.000)**	(0.000)**	(0.000)*
Population Age	-0.197	-0.196	-0.197	-0.260
	(0.061)**	(0.056)**	(0.056)**	(0.078)**
Whitaker Funding		0.043	0.047	0.055
(in millions)		(0.017)**	(0.018)**	(0.019)**
NIH Funding, t-1			0.001	0.001
(in millions)			(0.001)	(0.001)
Bayh-Dole Act				0.932
				(0.793)
Constant	-0.636	0.176	0.369	0.672
	(0.367)	(0.441)	(0.468)	(0.518)
Observations	39	39	38	38
Pseudo R-squared	0.33	0.37	0.37	0.37

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Model 2, which analyzes the effect of Whitaker funding on foundings, shows that as Whitaker funding increases, the number of bioengineering department foundings also increases significantly. The effects of density and population age remain significant in this model, and retain the same sign as in Model 1. The size of the coefficients on density and its square become smaller when Whitaker funding is introduced to the model. The goodness-of-fit of the model increases from Model 1 to Model 2.

Model 3 considers the effect of National Institutes of Health funding on the founding of bioengineering departments. The effect is positive, as expected, but is statistically insignificant and practically very small. Including NIH funding does not change the significance or direction of other variables; it also does not improve the fit of the model. Similarly, including the Bayh-Dole Act in Model 4 does not improve the fit of the model or introduce new significant information; the effects of density dependence and Whitaker funding remain significant. Bayh-Dole shows the expected coefficient sign, but is not significant in this model.

4.4 Discussion

Overall, these results provide strong support for the density dependence model and for the positive effect of Whitaker funding on the founding of bioengineering departments. There is evidence that the density dependence model holds in this population, and that density dependence effects are significant even after important elements of the institutional environment are included as controls. Density dependence is not explained away when the institutional variables are added, though controlling for institutional variables does reduce the magnitude of its impact.

Funding from the Whitaker Foundation is also significant across all models. The effect of funding from the Whitaker Foundation is interesting, because much of the funding was awarded not to sustain bioengineering research within departments, but with the specific purpose of founding departments. Actors within bioengineering assume that the Whitaker Foundation funded a process that was happening or that would happen anyway. As mentioned earlier, the Whitaker Foundation started investing significantly when the board noticed that the field was "at the cusp of becoming mainstream" (Grimm 2006). Similarly, Nerem claims that the Whitaker Foundation played an important role, but that institutional factors were also significant. This paper did not find other institutional factors to be significant – it found that the main drivers of bioengineering department founding were intra-population dynamics and funding from the Whitaker Foundation.

An interesting question that can be asked in relation to Whitaker Foundation funding is the extent to which it caused universities to simply rename research and educational programs that already existed, essentially giving an established structure to content that already existed, or whether it encouraged universities to establish these departments from the ground up, encouraging completely new research and programs. In the first case, if universities are simply renaming research that already exists, forming a department simply gives the population more structural inertia, and perhaps, greater weight in inter-population interactions. In the second case, the Whitaker Foundation could have encouraged the population of bioengineering departments to overshoot its resource environment. The Whitaker Foundation was primarily a source of resources for founding departments, not for sustaining them, and the Foundation has now closed. It is not clear that sufficient resources exist for supporting the population of bioengineering departments; partial evidence of this is the insignificance of NIH funding in the model of department founding. The possibility that the Whitaker Foundation caused the population of bioengineering departments to overshoot its resource constraints will be an interesting area for further research. As the population ages, it is possible that the population will be able to interact with the environment to create new resource opportunities; such interaction is predicted by the system dependence model (Lomi et al, 2005).

Neither NIH funding nor commercialization policy (Bayh-Dole) is found to be significant in the models tested. It is possible that the commercialization policy dummy variable is not significant because the introduction of the Bayh-Dole Act and the main drive towards university commercialization do not occur at the same time. Instead, the thrust for universities to become involved in commercialization may have occurred before the Bayh-Dole Act was passed. In fact, Mowery et al (2001) suggest that Bayh-Dole accelerated university commercialization that was already taking place, and that the extent of this acceleration is not clear.

Commercializable research is only one output of bioengineering departments. The primary output of university departments is students. The growth of bioengineering departments has implications for the labor market; as the number of bioengineering department grows, the number of graduates with degrees in bioengineering will also increase. On the one hand, it is possible that just as the departments could overshoot environmental resource constraints, they could also overshoot industry demand for graduates with bioengineering degrees. On the other, it has been claimed that bioengineering industry was born in university labs, and it is possible that generating graduates with degrees in bioengineering will open new market opportunities. An important extension of the work presented in this paper would be to consider the inter-population dynamics between bioengineering departments and biotechnology firms, as well as the effects of institutional embeddedness on foundings of bioengineering departments.

CHAPTER 5

AN ALTERNATIVE MODEL: STRATEGIC INTERACTION

5.1 Critique of Density Dependence Concept of Competition

Part of the appeal of the density dependence model is its simplicity and its clarity of concepts, but it has been criticized for being "just too simple a story" (Geroski, 2000: 616). While the concepts of competition and legitimacy are carefully defined and motivated, the definition of these concepts is quite limited. This poses a threat to the validity of empirical findings. It also provides opportunity for expansion of organizational ecology to consider broader definitions of competition and legitimacy.

Considerable work has been done to expand the definition and operationalization of legitimacy in relation to organizational ecology and density dependence. Simple density dependence analysis is based on an understanding of legitimacy that is limited to cognitive legitimacy. Institutional theorists have done considerable research to expand the use of an expanded definition of legitimacy that includes sociopolitical legitimacy. The concept has been expanded to include alternative measures that account for sociopolitical legitimacy by operationalizing legitimacy not only as density but also as the relational embeddedness of actors. There has been comparatively little work done to critique and expand the conception of competition in organizational ecology.

Density dependence is very clear its conception of competition as a diffuse and indirect process. This idea of competition is consistent throughout organizational ecology, though there have been recent efforts to expand the concept of competition to include direct competition (Witteloostuijn and Boone, 1997). In diffuse competition, organizations within a population compete for a similar resource base. As the number of organizations in a limited resource space increases, indirect competition increases regardless of whether individual organizations are aware of the identity or exact number of their competitors. When competition is understood to be diffuse, the density of the population is an exogenous variable. If the concept of competition within organizational ecology is expanded to include direct competition, density may be found to be endogenous.

An understanding of direct competition emphasizes that economic actors are not only aware of each other, but that they often act strategically to fight for market space. Organizational ecology does not consider direct competition, and it does not consider the possibility that organizations act strategically in founding decisions. I will consider strategic interaction between organizations more closely and consider whether there is evidence of strategic interaction in the population of bioengineering departments.

Organizational ecology does not address strategic interactions between organizations in a population and their effects on population dynamics, but it does not completely dismiss the organization as a strategic actor either. Baum and Shipilov (2006) write the following to explain organizational ecology's understanding of individual actors:

> Leaving aside whether their actions are intelligent or foolish, carefully planned or seat-of-the-pants, individuals can clearly influence their organization's future – but under conditions of uncertainty and ambiguity there are severe constraints on the ability of individuals to conceive and implement correctly changes that improve organizational success and survival chances reliably in the face of competition (58).

They then quote Hannan and Freeman (1984) to emphasize the organizational ecology view that adaptive efforts by organizations have outcomes that are "essentially random with respect to future value" (Baum and Shipilov, 2006: 58). Thus, the claim is not that organizations do not interact strategically or make strategic decisions; instead, it is simply that these strategic interactions have only a random or small impact on population dynamics such as founding, growth, and failure rates. I will consider the alternative: the possibility that strategic interactions have a systematic effect on population dynamics, specifically on the founding rate of bioengineering departments.

5.2 Endogenous Interaction and Competition

In making the decision to enter a market or adopt an innovation, strategic actors consider factors such as the cost and expected payoff of adoption. More importantly, strategic actors consider the expected adoption decisions of other actors in the same market space. It is not clear whether consideration of others' adoption decisions would lead to early or late adoption in the case of universities adopting bioengineering departments. In the first case, that of Cournot competition, there is an incentive for universities to adopt early. Early entry allows actors to capitalize on early gains, since profits per actor will decline with the number of firms that enter (Geroski, 2000). By this reasoning, if a university expects other universities to adopt bioengineering departments, it will adopt early in order to obtain the greatest payoff in terms of both students and research grants.

In the second case, in which knowledge spillovers exist, there is an incentive for universities to adopt later. In this case, universities wait until they are able to observe the success or failure of the early adopters. Those who adopt early provide a positive externality to those outside the market by making early investments and early mistakes from which other universities are able to learn. Later adopters can then make more accurate decisions about whether entrance will be profitable. Both of these scenarios emphasize an actor that strategically considers the expected behavior of other actors in the population, but they come to different conclusions about the pattern of adoption in a population. In order to understand which of these patterns is closer to the pattern that is exhibited in the population of bioengineering departments, it is important to explore strategic interaction of organizations in greater depth and to acquire tools for the analysis of endogenous interaction.

Witteloostuijn and Boone (1997) distinguish between endogenous and exogenous competition. Strategic competition is referred to as endogenous competition, which is described as "the result of increases in direct rivalry among firms within a population in the form of strategic moves" (17). Exogenous competition, on the other hand, is caused by changes in the environment, carrying capacity, and demand. Manski (2000) discusses social interactions rather than just competition and presents three hypotheses that empirical research has put forth to explain why actors belonging to the same population tend to behave similarly. Manski works from a framework of the economic analysis of social interactions, rather than from an organizational theory framework. The first hypothesis is endogenous interactions, which is Manski's main focus as well as the most important for the current discussion. According to the endogenous interactions hypothesis, the propensity of an actor to behave in some way varies with the behavior of the group. The second hypothesis is that of contextual interactions, in which the behavior of the actor in some way varies with exogenous characteristics of group members. The third hypothesis, correlated effects, proposes that actors have a propensity to act similarly to the group because the members of the group have similar characteristics or face similar institutional environments. Of these three hypotheses, only the endogenous interactions hypothesis implies feedback effects.

Though these three hypotheses are simple to distinguish conceptually, it is difficult to empirically distinguish between the three types of effects based on outcome data. According to Manski, "data on outcomes do not reveal whether group behavior actually affects individual behavior, or group behavior is simply the aggregation of individual behaviors" (2000: 128). This is referred to as the identification problem. Manski suggests several methods for identification, or, for distinguishing whether exogenous interactions exist within a group. These include: observing the dynamics of a process in which individual behavior varies with lagged values of group mean behavior, supposing that individual behavior varies in a specified nonlinear manner with group mean or median behavior, and using an instrumental variable that affects the outcomes of some, but not all, group members. Each of these methods depends on the ability of the researcher to correctly identify group composition (Manski, 2000: 129).

Before considering the identification of possible endogenous social interactions within the population of bioengineering departments, it worth mentioning another point that Manski makes. He writes that merely identifying endogenous interactions within a group is not helpful for purposes of policy intervention. In order to achieve effective policy intervention, it is important to distinguish between three types of endogenous interactions: constraint, preference, and expectations interactions (2000: 130). Constraint interactions occur when economic agents share a common resource. Preference interactions exist when an "agent's preference ordering over the alternatives in a choice set depends on the actions of others" (119). Finally, expectations interactions occur when an agent forms expectations by observing the actions and outcomes of other group members. Expectations interaction is a type of social learning. Manski explains the importance of distinguishing between preference and expectations interactions: policy "interventions that provide new information may alter the nature of expectations interactions… but should have no effect on preference interactions" (2000: 131).

5.3 Pattern of Acceleration Analysis

Instead of using one of Manski's recommended methods for identifying endogenous interactions within a group, I turn to an article by Peyton Young that presents and compares the pattern of acceleration of different models of innovation diffusion. Different patterns of innovation diffusion are shown to have unique patterns of acceleration, which provides a simple method for drawing initial observations about the presence of endogenous interactions in the population of bioengineering departments. Young analyzes rates of innovation diffusion rather than the rate of innovation adoption, but it is simple to think of the founding of bioengineering departments as a process of innovation diffusion. It merely requires defining a larger population from which a certain proportion of universities have adopted bioengineering departments and others have not, at a specific time, t. Defining a larger population would pose a problem for firms, but bioengineering departments are likely to be founded only at universities and primarily at research-intensive universities. I define the larger population according to the Carnegie Foundation for the Advancement of Teaching classification of a group of universities as Doctoral/Research Universities-Extensive universities. There are alternative methods of defining the larger population, but this is sufficient for the purpose of this paper, which is simply to compare the pattern of bioengineering department founding to Young's models of innovation diffusion.

Young (2007) presents five models of innovation diffusion: inertia, contagion, conformity, social learning, and moving equilibrium. *Inertia* is the simplest model; actors delay adoption until a revision opportunity occurs. In the *contagion* (or, epidemic) model, actors adopt an innovation when they hear about it from someone who has already adopted. *Conformity* (or, threshold) models explain innovation diffusion as a process by which people adopt and innovation when enough other people in the group have adopted the innovation. In the *social learning* model, actors adopt when they see enough evidence among prior adopters to convince them of the worth of the innovation. Finally, *moving equilibrium* models attribute the process of innovation diffusion primarily to changing external conditions.

Young develops adoption functions for each of these models, and from the adoption function derives predictions about the rate of acceleration and the relative rate of acceleration of each model. He finds that "each family of models has a distinctive pattern of acceleration" and suggests that these patterns can be used to determine the type of heterogeneity that is driving a particular diffusion process (2007: 34). This is a useful method of conducting an initial analysis of endogenous interactions of a population. Three of the five models include feedback effects; these are the contagion, conformity, and social learning models. In the contagion model, individual organizations interact with other organizations in the population by hearing about innovations. There are two sources of information about innovations: sources within the group and/or sources external to the group. The rate of innovation adoption depends on the rate at which a non-adopter hears about the innovation. The conformity model emphasizes individual thresholds that determine when a particular agent will adopt. Feedback effects exist because unique individual thresholds are expressed as a function of the proportion of the population that has already adopted.

The model that most strongly emphasizes strategic interaction and feedback between group members is the social learning model. According to the social learning model, individuals are not simply concerned with the number of previous adopters. They are concerned with evidence and outcomes among previous adopters. Young makes a distinction between non-cumulative and cumulative learning models. In the cumulative learning model, the information generated by each prior adopter accumulates over time. In other words, in addition to taking into account the outcomes of the previous adopters, the cumulative learning model emphasizes that an individual considering adoption will also consider the length of time that the previous adopters have used the innovation. Non-cumulative learning models are classified together with threshold models. Cumulative learning curves have the unique feature of initial deceleration. Young explains that "cumulative learning attaches a lot of weight to information generated by very early adopters, of which there are very few, which creates an initial drag on the process" (2007: 19). Figure 5.1 shows a comparison of adoption curves generated by non-cumulative and cumulative learning.

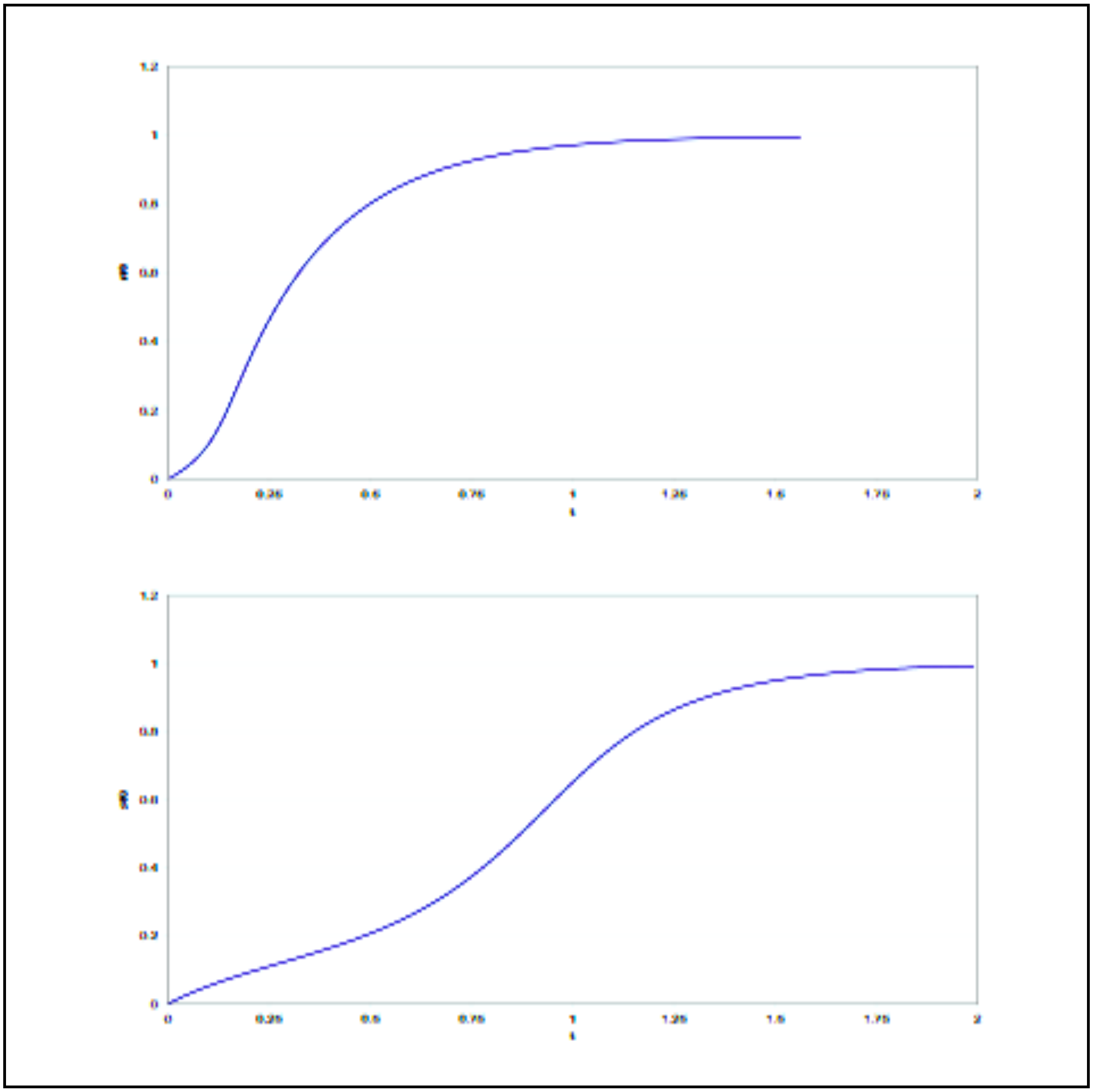

Figure 5.1 Acceleration Patterns of Cumulative and Non-Cumulative Learning
A comparison of the patterns of innovation diffusion caused by non-cumulative (top) and cumulative (bottom) social learning. Source: Young (2007: 20)

Because several of these models (in particular the cumulative social learning model) are driven by endogenous interaction, it is possible to conduct an initial analysis about whether strategic interaction has an effect on the founding rate of bioengineering departments. Furthermore, it is possible that this analysis will provide evidence not only of the existence of endogenous interaction in the population of bioengineering departments, but of a particular type of endogenous interaction. The contagion and conformity models can be classified as endogenous preference interaction. The social learning model can be classified as endogenous expectations interaction. There is an especially strong association between the learning model and expectations interaction. Endogenous expectations interaction is based on observational learning.

Table 5.1 presents Young's acceleration analysis findings.

Table 5.1 Acceleration Analysis Models

Model	Footprint	Restrictions on distribution
1. Inertia	$\ddot{p}(t) < 0$	none
2. Threshold	$\dddot{p}(0) > 0$ $\ddot{p}(t) / \dot{p}(t) \uparrow$ initially	density initially increasing and greater than unity
3. Cumulative learning	$\ddot{p}(0) < 0$ $\dddot{p}(t) / \dot{p}(t) \uparrow$ initially	none density initially increasing
4. External moving equilibrium $F(\theta(t))$	$\dddot{p}(0) > 0$ $\ddot{p}(t) / \dot{p}(t) \downarrow$ initially	density initially increasing and logconcave; $\theta(t)$ linear
5. Contagion	$\dot{p}(t) / p(t) \downarrow$ $\ddot{p}(t) / \dot{p}(t) < (1 - 2p(t))h(t) / p(t)$	none

Source: Young (2007: 35)

In this table, $\ddot{p}(t)$ indicates the rate of acceleration and $\ddot{p}(t)/\dot{p}(t)$ indicates the relative rate of acceleration. In Young's analysis, $p(t)$ is the proportion of adopters at time t, where the clock is set so that $p(0)=0$. Therefore, $\ddot{p}(0)$ indicates the rate of acceleration at time $t=0$. The cumulative learning model is the only model in which $\ddot{p}(0)$ is less than zero. Also, this model has a relative rate of acceleration that is initially increasing.

In order to compare the acceleration pattern of bioengineering department founding to the unique footprints of these models, I plotted the founding curve as a proportion and calculated the rate of acceleration and the relative rate of acceleration. A graph that includes the adoption curve and the rate of acceleration is shown in Figure 5.2.

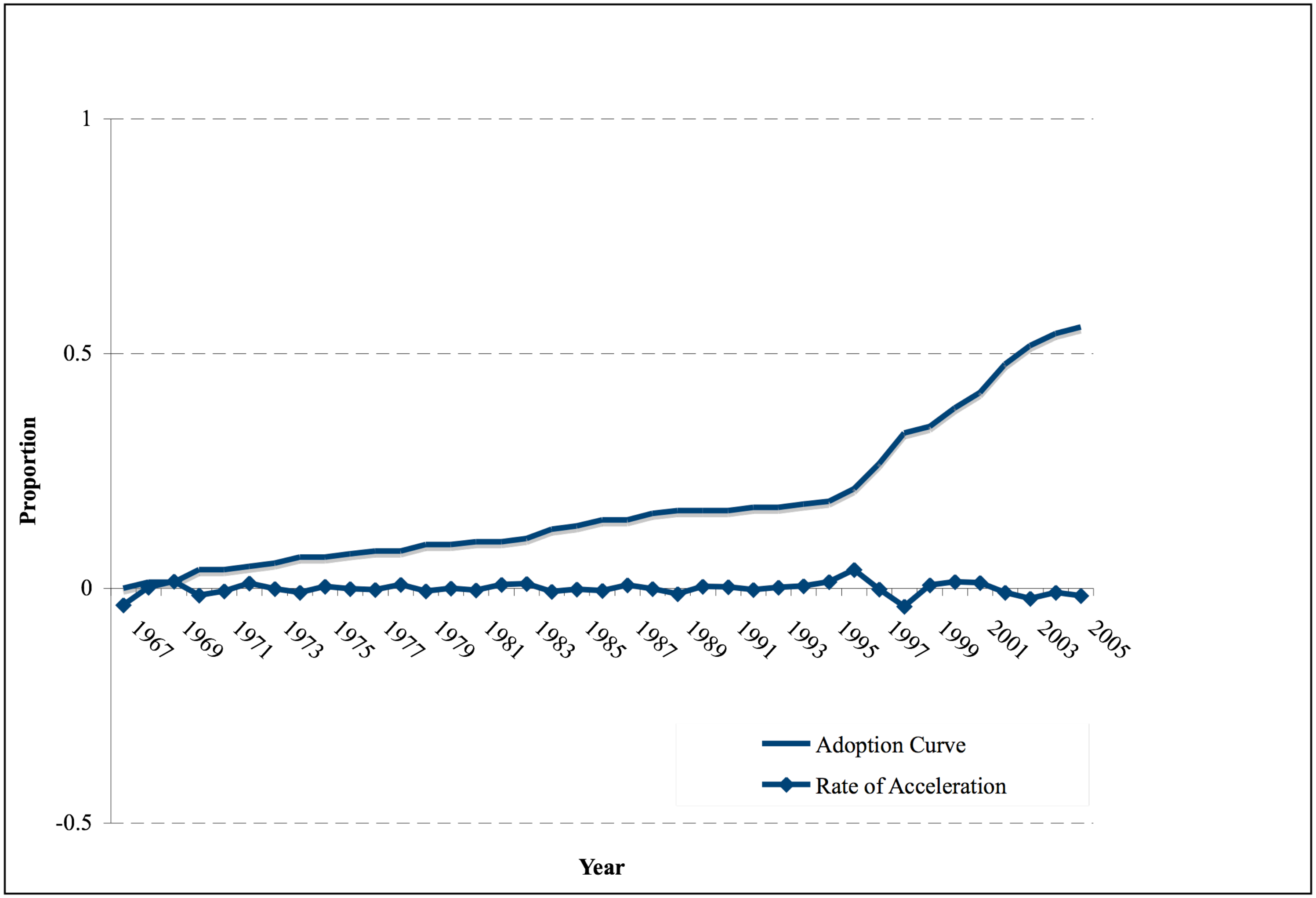

Figure 5.2 Acceleration Analysis of Bioengineering Department Founding

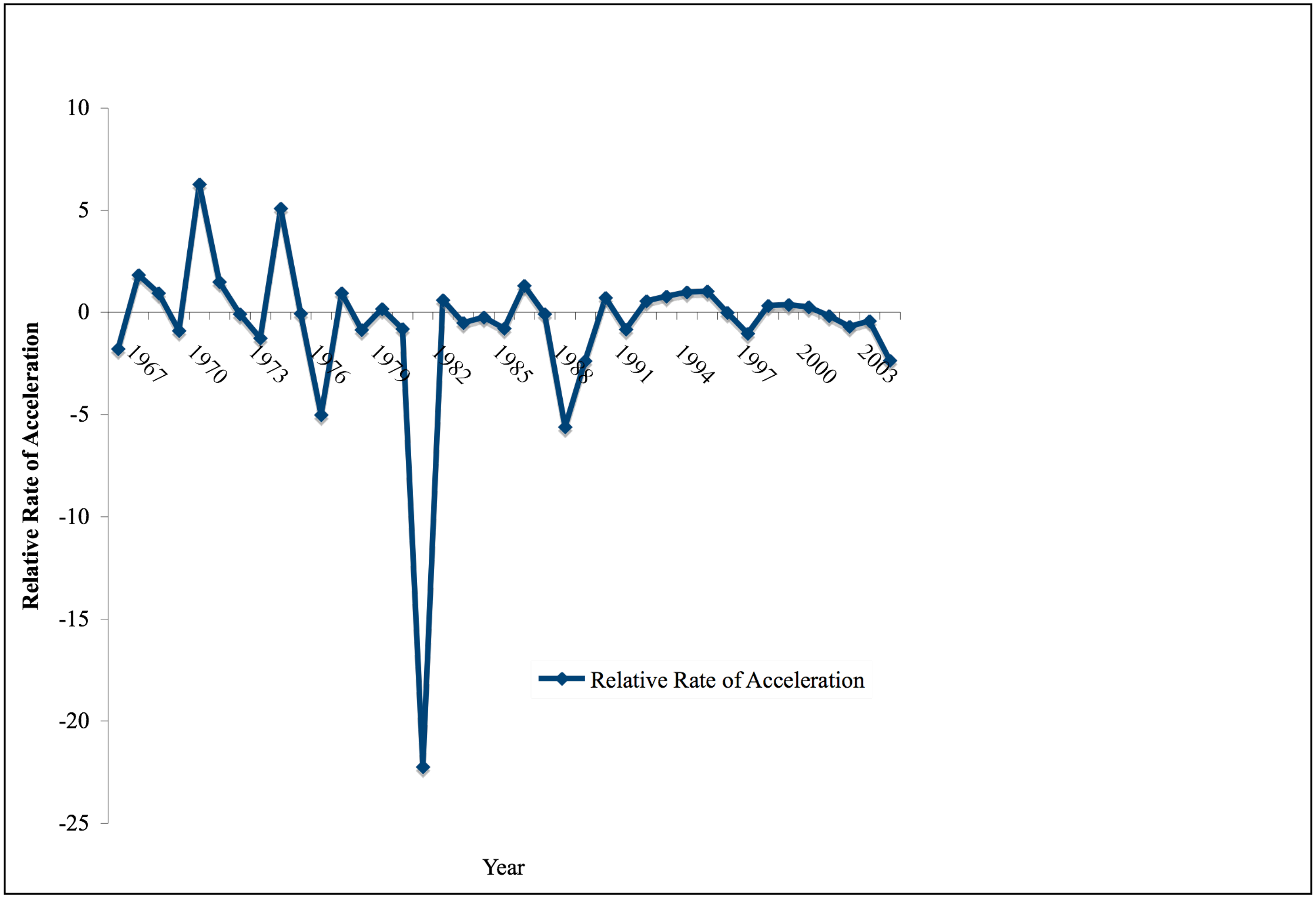

Figure 5.3 Bioengineering Department Founding: Relative Rate of Acceleration

Figure 5.3 shows a graph of the relative rate of acceleration, $\ddot{p}(t)/\dot{p}(t)$. Both Figure 5.2 and Figure 5.3 provide evidence that the acceleration pattern of bioengineering department founding matches the acceleration pattern of the cumulative learning model. This provides strong initial evidence that strategic interaction has affected the founding pattern of bioengineering departments. It also provides evidence that strategic interaction in this particular population leads to later adoption (rather than the early adoption predicted by Cournot competition).

An important implication of the first finding (that strategic interaction has an impact on the founding rate of bioengineering departments) is that the density variables used in the density dependence analysis earlier in the paper are most likely endogenous and, therefore, biased. This does not rule out the use of density as a variable in organizational analysis. It simply calls for a different approach, such as the use of an instrumental variable.

CHAPTER 6

CONCLUSIONS

This paper has shown that there is evidence of both density dependence and strategic interaction effects on the founding rate of bioengineering departments, but further research is needed to improve the validity and explanatory power of these models. The validity of the density dependence model is threatened by evidence of strategic interaction between actors, which implies that density is endogenous. The strategic interaction model is a simple tool for drawing initial observations about the factors that influence an innovation diffusion process.

Finding evidence of the effect of strategic interaction within the university bioengineering department population raises questions of other sources of strategic interaction that could influence the founding rate of the bioengineering population. The introduction of this paper notes the unique interdependence of organizations within high-tech communities such as the bioengineering community. If social learning has had a significant effect on the founding rate of bioengineering departments, there is no reason to assume that learning only occurred by universities observing other universities. In short, Manski's concern with researchers correctly identifying the group within which endogenous interaction takes place is relevant.

The density dependence analysis found Whitaker funding to be highly significant in explaining the founding rate of bioengineering departments. It is possible that the Whitaker Foundation also acted strategically; there is evidence in a quotation mentioned earlier in the paper that the board of the Whitaker Foundation made the largest contributions to department foundings when they felt that the population was on the cusp of significant growth. If this is the case, the significance of Whitaker funding could be overestimated. This does not diminish the concern that Whitaker funding could contribute to the population of bioengineering departments overshooting its carrying capacity; it simply gives more weight to these concerns. It would be interesting to develop a model that analyzes both the effects of cumulative learning and Whitaker funding.

Another issue in relation to funding by the Whitaker Foundation is the selection criteria that were used to make funding decisions. Even if the Whitaker Foundation would not disclose information about their specific selection process, it would be interesting to analyze whether there is a relationship between a school having an already-established bioengineering program and receiving a grant. It should also be noted that the fact that some schools implemented programs before they established departments causes a selection issue in the founding analysis. If universities implement programs to gauge the potential success of a department, the universities that try and die out are selected out of the analysis of departments, and again, the positive effect of Whitaker is possibly overestimated.

In spite of the limitations of this study, this paper makes an important argument that the use of the concept of competition in organizational ecology is limited, and presents evidence that strategic interaction influenced the pattern of bioengineering department founding. There is evidence that the strategic interaction that influenced the pattern of bioengineering department founding was the result of a cumulative learning process, which can also be referred to as endogenous expectations interaction. This particular model of endogenous interaction is similar to density dependence because both predict that the initial founding process is very slow. In the density dependence explanation, this is due to the lack of legitimacy for the organizational form. Time is required to establish a sufficient base of legitimacy. In the cumulative learning model, the initial slow phase is due to the lack of information about adoption outcomes. Time is required to establish a sufficient base of information. Further analysis is necessary to draw a conclusion about which explanation has more empirical weight.

Further research is also necessary to draw conclusions about the existence of strategic interactions and cumulative social learning in other populations. A population of universities might be more likely to be influenced by social learning than a population of firms would. Social learning is perhaps more pervasive in university environments, which are characterized by high turnover as former students of one university department often become professors at another university. Other forms of strategic interaction might be more prevalent in populations of firms.

In summary, this paper is unique because it addresses both a population and a concept that have received little attention within organizational ecology. Populations of universities and university departments are not often studied, nor has organizational ecology's conception of competition been thoroughly critiqued. The analysis conducted in study provides evidence that more detailed and robust comparisons of population ecology and strategic interaction are likely to yield important conclusions about the factors that influence population dynamics.

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